N88-16655

INTEGRATED DIAGNOSTICS

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INTRODUCTION - STATEMENT OF NEED

The challenge now facing our military strategists is how to overcome the ever-increasing gap between the strength of our adversaries and that of our own existing forces. To lessen this gap, our weapon systems have become more complex and costly as a result of the increased demand for performance and in design. Both of these factors tend to exacerbate the maintenance problems. Fault location (diagnostics), in particular, is a maintenance task that is greatly affected by complexity and cost. Increased system complexity generally makes the fault location task more difficult, particularly when the basic skill level and capability of the maintenance personnel do not improve at the same rate as system performance. However, the increased cost of aviation systems and related spare parts requires that aircraft downtime be kept to an absolute minimum and that false removals of major components be reduced as much as is practical without sacrificing fault-detection capability.

Fortunately, the technological advances that lead to improved system performance can also be used to enhance system supportability. Advanced condition monitoring sensors, such as accelerometers and oil debris detectors, often permit maintenance personnel to detect and isolate a failed component soon after operation. Built-in test (BIT) and built-in test equipment (BITE) can also provide similar capabilities for electronic systems, provided the input parameters, test point location, and decision logic are correct (this will be further discussed).

The increasing sophistication of modern aircraft, the need for greater aircraft availability, and the limited pool of manpower and skills available for maintenance have placed excessive demands on current diagnostic philosophies. In actual process, no systematic approach to fault isolation is employed (Fig. 1). The test procedures in the technical manuals are often ignored, and "remove and replace" becomes the standard troubleshooting process. This may evolve into a total "shotgun approach," where all possible failed components are replaced. The complexity and unreliability of the field test equipment lead to their misuse and erroneous results. Even BIT indications are misinterpreted when fault codes must be interpreted and referenced in manuals.

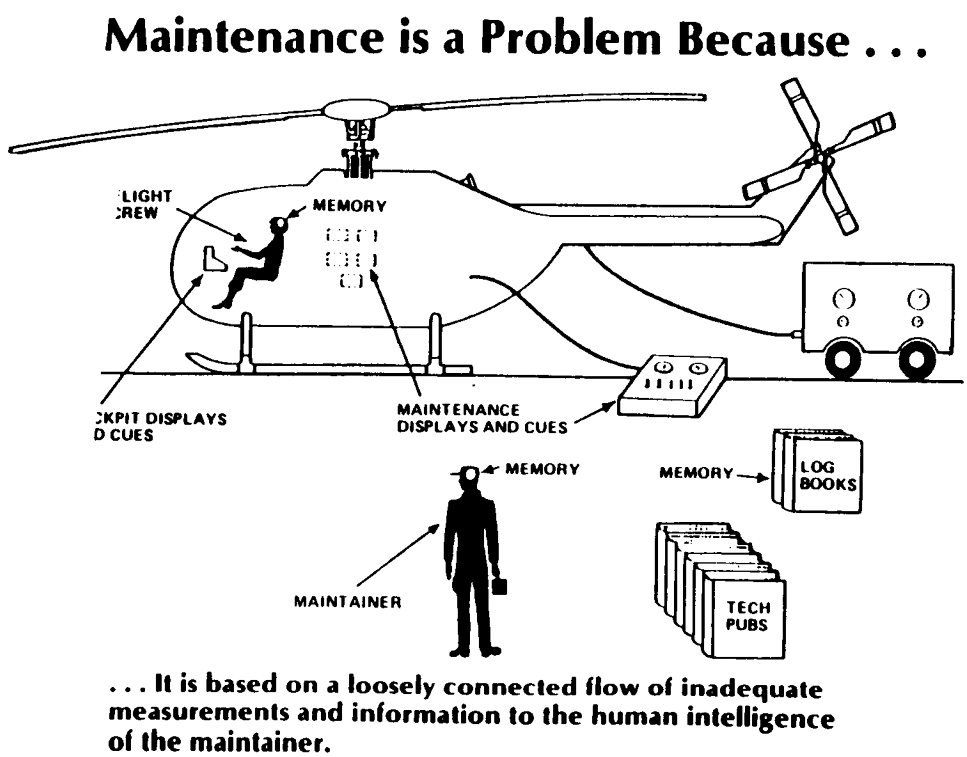

Fig. 1. General condition at AVUM level maintenance.

If the elements of Fig. 1 could be tied together and offer a coherent picture of the status of the aircraft and isolate to failed components, then an integrated diagnostic system would be realized. The objective of such a system is the transformation of available data, whether from the crew, cockpit, TM's or test equipment, into useful maintenance information. The system should be able to evaluate the usefulness of the data, reject incorrect or superfluous data, and aid the personnel in the determination of the proper maintenance action. The current approach depends heavily on the experience and training of the crew and maintenance personnel to both acquire and interpret the many forms of data available. This leads to a specialization of tasks and thus the requirement for a large number of skill specialties. An integrated diagnostic approach has the potential to reduce the number of skill specialties now required and thus allow the maintenance of current capabilities even after reduction in force structure.

Another important reason for integrated diagnostics and also for condition monitoring systems was aptly detailed in a NASA study on the potential causes of pilot-error accidents. U.S. Army statistics have identified human error as the major cause in approximately 75% of all major helicopter accidents during the fiscal years 1978-1982. Table 1 is a summary of the results of a a NASA study in which 110 randomly selected U.S. Army accidents were reviewed. These accidents were from the following categories: Class A accidents (those resulting in a fatality, permanent disability, airframe loss, or costs exceeding $500,000) and Class B accidents (hospitalization of five or more personnel, permanent partial disability, or costs between $100,000 and $500,000).

TABLE I

SUMMARY OF HELICOPTER PILOT ERROR ACCIDENTS[3]
AGGREGATED BY AREAS OF TECHNOLOGY NEEDS[2]

AREAS OF TECHNOLOGY NEEDS	NUMBER OF MISHAPS	NUMBER OF FATALITIES	NUMBER OF INJURIES (NONFATAL)	COST ESTIMATES AMOUNT	PERCENT
NO APPARENT TECHNOLOGY IMPLICATIONS	5	0	15	$ 5,828,440	9.3
ALTERNATIVE TO THE TAIL ROTOR	6	0	8	1,768,799	2.8
ADVANCED FLIGHT SIMULATORS	21	5	17	13,216,403	21.1
ADVANCED FLIGHT CONTROLS AND DISPLAYS	25	8	23	15,394,824	24.6
OBSTRUCTION DETECTION	20	13	42	11,962,376	19.1
AUTOMATED MONITORING & DIAGNOSTIC SYSTEMS	29	7	41	12,022,725	19.2
CONTINGENCY POWER	4	0	9	2,446,922	3.9
TOTALS FOR RECORDS REVIEWED[1]	110	33	155	$62,640,494	100.0

NOTES: (1) RANDOM SELECTION FROM ARMY CLASS-A AND -B ACCIDENTS 1981-1983.
(2) NASA STUDY
(3) HUMAN ERROR IS CAUSE FACTOR IN 75% OF ALL MAJOR ARMY ACCIDENTS 1978-1982. PUBLISHED IN RWI, APRIL 1986.

As the table indicates, 29 accidents, or 26.6%, were identified in the NASA study as preventable with new technology to assist the pilot in monitoring the performance of flight-critical systems; i.e., automated monitoring and diagnostic systems. Researchers noted that numerous accidents involved a sequence of events wherein an actual or suspected in-flight failure was misinterpreted by the pilot/crew or incorrectly diagnosed. These findings led to recommendations for advanced technology to:

1. Monitor flight-critical systems without pilot intervention.

2. Warn of adverse trends and impending system failure.

3. Correlate information or malfunctions.

4. Automatically predict and monitor performance capabilities and power demands to assist the pilot in operating within performance limitations.

This paper summarizes recently completed projects in which advanced diagnostic concepts have been explored and/or demonstrated. The projects begin with the design of integrated diagnostics for the Army's new gas turbine engines, and advance to the application of integrated diagnostics to other aircraft subsystems. Finally, a recent project is discussed which ties together subsystem fault monitoring and diagnostics with a more complete picture of flight domain knowledge.

ENGINE DIAGNOSTICS

APPROACH

The successful fielding of the T-700 engine demonstrated the importance of incorporating maintenance and diagnostic technologies at the start of the design phase and not trading off this technology for other considerations (cost and/or weight) as the engine matured. The results of this have shown the T-700 engine to be one of the most maintainable engines within DOD inventory. This philosophy of designing in diagnostics was carried over to other engine development programs--the advanced technology demonstrator engine program (ATDE) and the modern technology demonstrator engine (MTDE). Under these efforts, the contractors were required to conduct diagnostic and condition monitoring studies to assess and identify specific diagnostic and monitoring techniques that would allow on-condition maintenance yet not sacrifice the safety of the pilot and crew. Fault isolation procedures were to be developed to identify faults to the modular or line replaceable unit (LRU) level.

From these studies, a diagnostic/condition monitoring system was defined beginning with a determination of the right mix of sensor inputs. Parameter selection was first based on the data that would normally be available from electronic fuel controls and cockpit indications since these signals were essentially free for diagnostic usages. Typical signals are listed in Table II. Additional parameters could then be selected on the basis of their usefulness/effectiveness within a given system. This is determined by system complexity, cost to monitor, and potential payback. The functions of the monitoring system can be generalized into:

1. General engine health.

2. Engine limit exceedances.

3. Engine trending analysis.

4. Fault isolation to the LRU/module level.

5. Low cycle fatigue.

6. Hot section stress.

Table III is a compilation of the various types of parameters required for the above specific areas. The final selection of parameters is obviously dependent on system complexity. To determine which mix of parameters and techniques should be pursued, studies were conducted on system effectiveness vs. cost tradeoffs. Possible engine parameters, sensors/transducers and maintenance indicators, and ground support equipment combinations were identified and the cost and effectiveness of each were determined.

TABLE II

TYPICAL PARAMETERS

CONTROL UNIT

T2 - COMPRESSOR INLET TEMP
NG - GAS GENERATOR SPEED
NP - POWER TURBINE SPEED
Q - TORQUE
PTIT - POWER TURBINE INLET TEMP
P3 - COMPRESSOR DISCHARGE PRESS
ΔPFF - FUEL FILTER ΔP SWITCH
ECUF - ECU FAULT OUTPUTS

PLA - POWER LEVEL ANGLE
KIAS - KNOTS INDICATED AIR SPEED
PI - AMBIENT AIR PRESSURE
C/P - COLLECTIVE PITCH ANGLE
NR - ROTOR SPEED
G - AIRFRAME G LOAD

COCKPIT

POIL - OIL PRESS
TOIL - OIL TEMP :
LOIL - OIL LEVEL
ΔPOF - OIL FILTER ΔP
CHIP - CHIP DETECTORS
WF - FUEL FLOW (CALCULATED)
TFUEL - FUEL TEMP
AICE - ANTI-ICE SWITCH

EMS

IPS - INLET PARTICLE SEPARATOR SWITCH
CVIB - COMPRESSOR VIBRATION
TVIB - TURBINE VIBRATION
WOW - WT ON WHEELS SWITCH
BLEED - CUSTOMER BLEED SWITCH

TABLE III

PARAMETER REQUIREMENTS

	T1	P1	NG	NP	Wf	Q	MGT	TBT	CDP	EECf	POIL	TOIL	LOIL	ΔPOF	ΔPFF	M PLUG	VIB 1	VIB 2	VIB 3	IGN	MAN
ENGINE GENERAL HEALTH	X	0	X	X	0	X	X	0	0		X			X	X	X	0	0	0		
OPERATING PARAMETER EXCEEDANCE			X	X		X	X														
ENGINE LRU FAULT ISOLATE																					
CONTROL SYSTEM LRU'S	X	0	X	X	0	X	X	X	X	X					X					0	0
OTHER LRU'S	X		X	X		X	X	X	X	X	X	0	0	X		X					
ENGINE TREND ANALYSIS	X	0	X	X	0	X	X		0		0	0					0	0	0		
LOW CYCLE FATIGUE			X	X																	
HOT SECTION STRESS							X	0													
OVERALL	X	0	X	X	0	X	X	X	X	X	X	0	0	X	X	X	0	0	0	0	0

MINIMUM REQUIREMENT=X BEST CONFIDENCE=0

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The various mixes of combinations are depicted in Fig. 2. Systems 1 and 2 consisted of sensors, cockpit indication, and a maintenance indicator unit for the airborne portion of the system. System 3 added a data recorder/analyzer. All systems used a portable data analyzer for ground support at the unit maintenance area with systems 2 and 3 adding a processing station at the intermediate level. System 3 was capable of interfacing with an airframe recorder if needed.

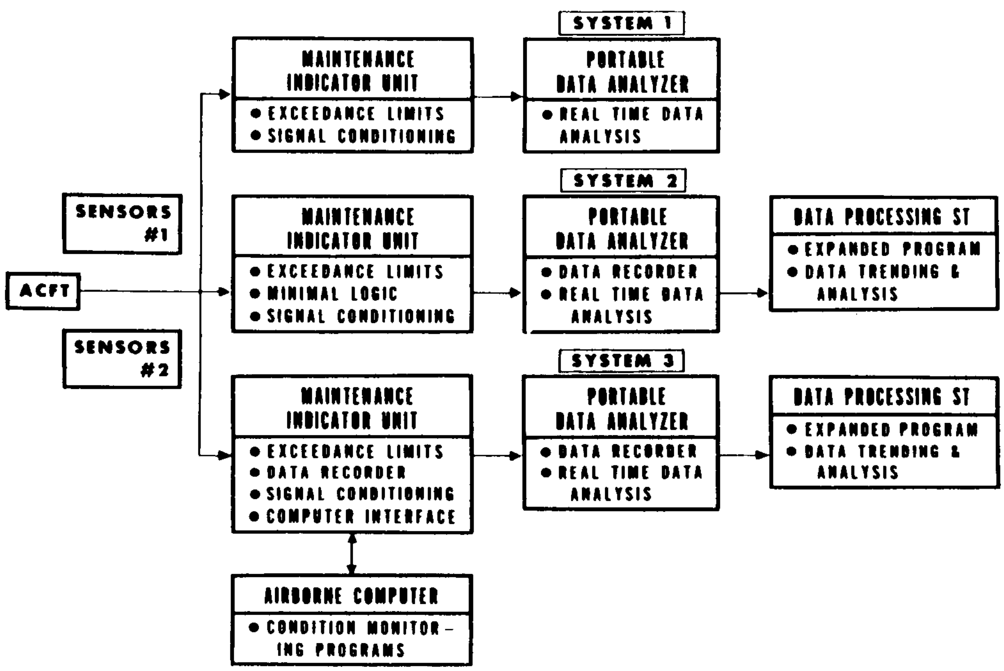

Fig. 2. Condition Monitoring Concepts

System 1 is the least complex with minimum hardware and a "no frills" approach. It requires active participation by maintenance personnel in most of the fault isolation process. All components of this system would be found at the unit maintenance level.

System 2 would have an expanded data analysis capability to reduce the human input in the fault isolation process and thereby decrease the overall possibility for erroneous maintenance decisions. This system includes a data processing station at the intermediate maintenance level to analyze the data from the ground analyzer unit. This approach offers several advantages over the system initially described. The added airborne logic capability allows this system to isolate more malfunctions to cause. Field operation of this system would not require additional ground support equipment and the need for additional dynamic testing by the portable data analyzer is reduced. Data from the portable analyzer could be further analyzed at the processing station for further fault isolation and repair.

System 3 represents a maximum capability for condition monitoring. It would virtually eliminate the need for manual malfunction troubleshooting.

An airborne recorder/analyzer would be added with this system along with an increased number of sensors. The recorder would be installed to record flight and exceedance/malfunction information. The data processing station would have data trending capability as well as fault isolation software.
The maintenance philosophy for this system is a maximum analysis approach and requires the least human analysis and action of the three systems discussed. With extended in-flight condition monitoring and analysis, this system will predict many types of failures to reduce in-flight emergencies and mission aborts. Data from the cockpit display and airborne recorder would be analyzed either on board or at the data processing center, thus eliminating the need for the portable analyzer and other ground support equipment.

SYSTEM EFFECTIVENESS

The three systems were evaluated on their diagnostic effectiveness in terms of maintenance actions. The objective of the evaluation was to determine the overall probability of diagnosing known faults based on the individual system concepts and the engine parameters being monitored. In addition, costs for each system were established to give a system cost v.s. effectiveness comparison.

Fig. 3 shows the results of this evaluation and indicates that an intermediate complexity system, such as No. 2, provides the most diagnostic effectiveness at the least cost. System No. 1 requires a high degree of mechanic interaction for fault isolation without sufficient monitoring information or analysis capability. Therefore, the mechanic must rely on the diagnostic procedures in his tech manuals and on his own experience. Too often this results in erroneous decision-making and a lack of diagnostic effectiveness. The most complex system, No. 3, provides the most diagnostic effectiveness. However, there is an increase in cost of over twice that of System No. 2, primarily due to the requirements for an airborne recorder/analyzer. In addition, a drawback of System No. 3 is the extensive automatic analysis and decision-making capability of the system itself. As depicted in Fig. 4, a major driver of support costs is misidentification of good components as bad. The probability of this occurrence is very high for complex components. Fig. 5 shows a more responsive approach than a completely analytical one. Here automatic decision processes will be utilized when sufficient data on the system condition is known. Otherwise, the system must be flexible to allow the maintainer to use his judgment and experience in identifying and correcting malfunctions.

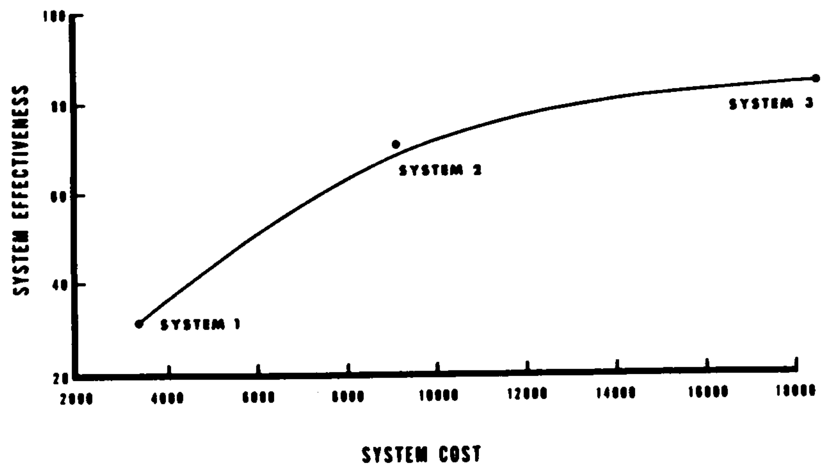

Fig. 3. Condition Monitoring Effectiveness

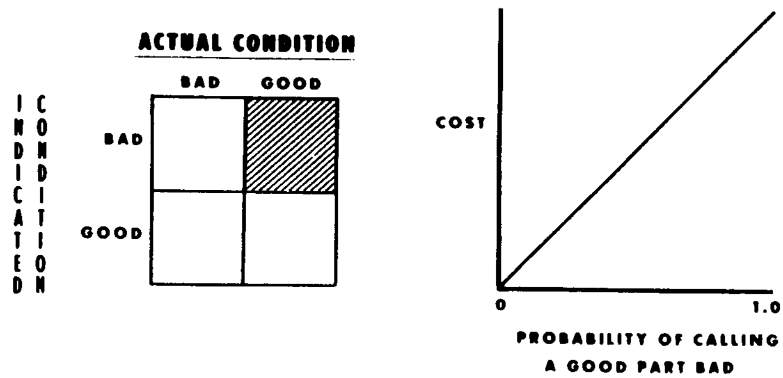

Fig. 4. The Automatic Diagnostic System Dilemmma

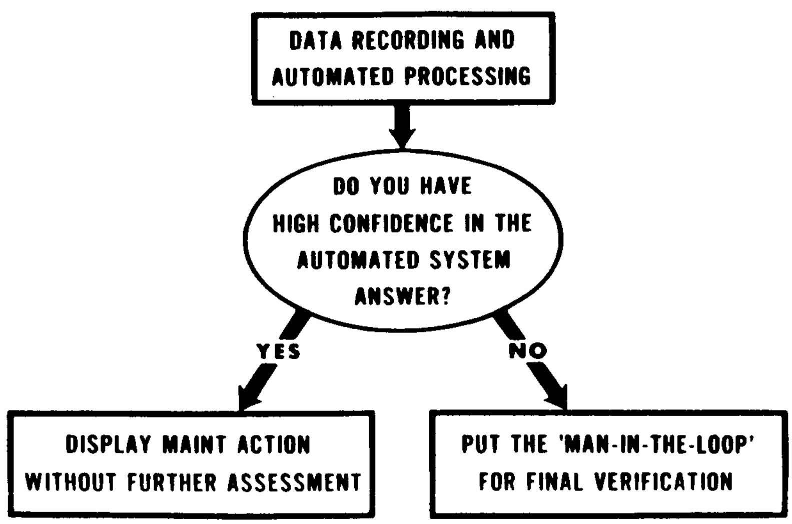

Fig. 5. Optimum Approach

ADVANCED MAINTENANCE DEMONSTRATION

DESCRIPTION

The capability of achieving a fully functional integrated diagnostic system is dependent on the incorporation of an airframe recorder/processor for real time data assessment and indication to the pilot and mechanic. However, as indicated during the engine diagnostic programs, such a system is cost prohibited if only applied to the powerplant subsystem. However, if the hardware could be used in a multifunction role, then the costs could be shared with other subsystems and the benefits increased to justify the overall procurement costs. Such a system was pursued and demonstrated under an Army program called "Advanced Maintenance Demonstration" (AMD).

The AMD was initiated in 1985 as an ambitious 4-year effort to enhance the diagnostic and condition monitoring capabilities of current and future helicopter weapon systems. This effort is comprised of building blocks from "off-the-shelf" technology and new technology applications. These building blocks are depicted in Fig. 6 and include an airborne data recorder/processor, ground-display computer systems, and advanced diagnostic/prognostic software logic using aritificial intelligence (AI) techniques. The key to achieving a successful diagnostics system is the integration of these technologies with a close regard for the human engineering disciplines; that is, how the mechanic in the field during combat can best utilize the data available to him. The system must be able to translate these vast amounts of data to useful, nonconfusing information.

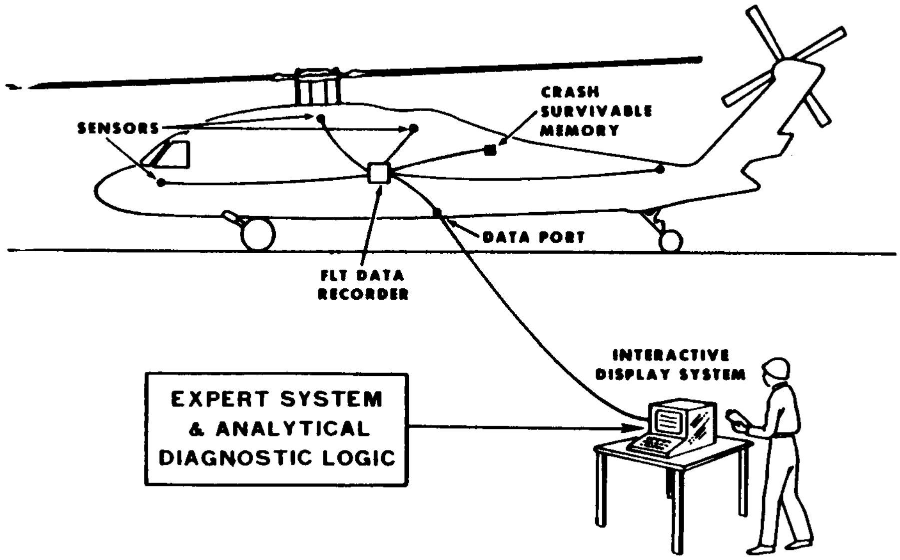

Fig. 6. AMD Approach

As previously mentioned, the key to justifying the hardware costs of such a system is by applying the equipment in a multifunctional manner. The recorder/processor is no longer monitoring just the engine, but must record and process data from the other dynamic susbsystems plus the critical airframe components. Fig. 7 shows the integration of these various functions along with a crash survivable memory function and advancing technologies such as expert systems. The recorder/analyzer not only records parametric information but also provides diagnostic/prognostic analysis of equipment status and display to the cockpit and mechanic. The system also becomes a repository for the avionics built-in-test (BIT) data.

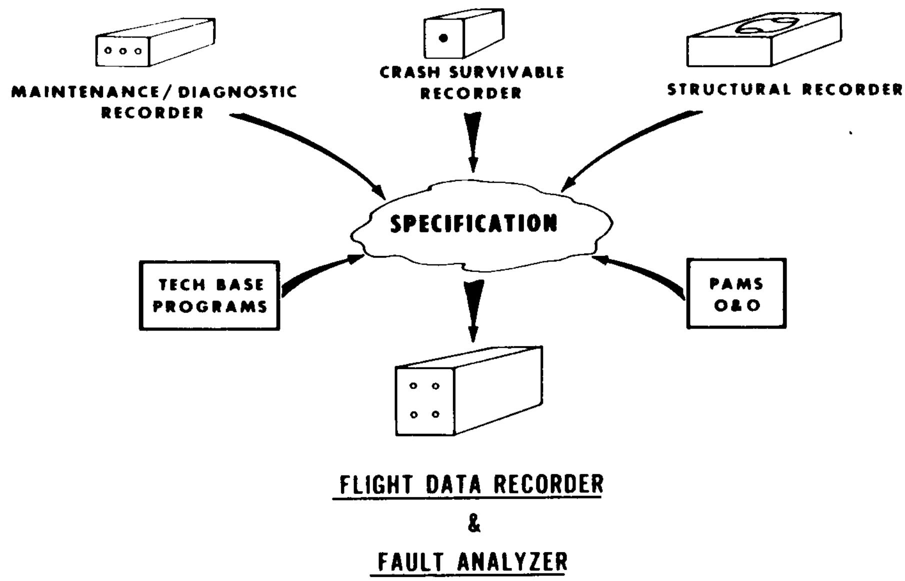

Fig. 7. Program Integration

Another essential piece of the system is an interactive maintenance aid that will guide the mechanic through sophisticated troubleshooting logic (structured around AI), as well as sort, analyze, and display data accumulated from the recorder such as exceedance or fault code data. The system must be a skill enhancement tool that can also be used for skill retention and on-the-job training, as well as interface with other computer equipment such as the automated log book (ALB) and unit level computer (ULC) systems. Figure 8 depicts the display system being used for the demo. Although this system is required to download the data from the aircraft, a production system uses a data transfer cartridge that would fly with the aircraft.

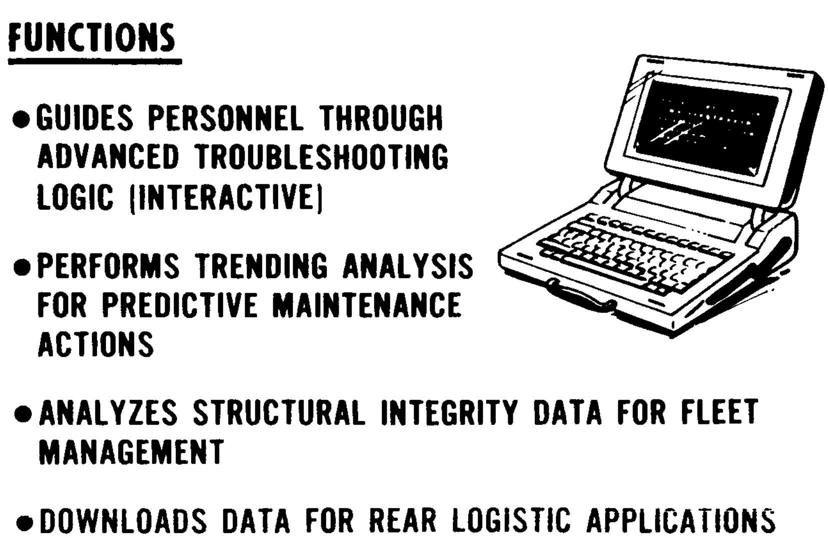

Fig. 8. Interactive Maintenance Aid

However, the most important component of any diagnostic system is the software--the decision logic which ultimately guides the mechanic to the correct maintenance action. Recorders, processors and color graphic displays can be very advanced to the point of complete automation or even voice activation. However, they become burdensome tools if the logic cannot distinguish a good versus a bad component. The software for the AMD diagnostic logic uses available techniques based on typical analytical procedures as well as AI techniques using expert systems procedures.

The AMD system was placed on AH-64 and UH-60 aircraft. The system involved the recording of selected parameters from the dynamic and structural components. To restrict excessive costs, every effort was made to utilize existing sensors. In order for this to be successful, the functions of the system had to first be defined. These included:

(1) Exceedance data from engine, rotor, drivetrain, etc. This data is to be analyzed and stored for pilot advisory as well as mechanic retrieval.

(2) Engine performance data to predict powerplant capabilities and to automatically perform "hit" checks.

(3) Engine usage and trend data.

(4) Structural usage data.

(5) Flight regime recognition data.

(6) Data for gross weight estimation.

(7) Load severity data.

(8) Life assessment data to calculate damage accrual rates.

(9) Component operating data for troubleshooting and inspection queuing.

(10) Accident and crash investigation data.

Tables IV and V list the various parameters for the UH-60 and AH-64 respectively. The AH-64 multiplex (MUX) bus traffic provided approximately 600 digital data points for diagnostic/condition monitoring purposes. This data was recorded at appropriate rates to preserve resolution and fidelity. Since recorders can only provide a finite storage capability, various compression techniques must be utilized. Data from vibration and direct strain measurements must be conditioned prior to recording due to the higher sample rates for such signals.

TABLE IV

UH-60A PARAMETERS (40 TOTAL)

CONTINUOUS (24 TOTAL)	DISCRETE (16 TOTAL)
ALTITUDE (BAROMETRIC)	#1 ENGINE OIL PRESSURE
ALTITUDE (RADAR)	#2 ENGINE OIL PRESSURE
ALTITUDE RATE	#1 ENGINE CHIP DETECTOR
AIRSPEED	#2 ENGINE CHIP DETECTOR
#1 ENGINE TORQUE	ENGINE FIRE
#2 ENGINE TORQUE	APU OIL PRESSURE
#1 ENGINE RPM (NG)	SAS WARNING
#2 ENGINE RPM (NG)	#1 ENGINE HYDRAULIC PUMP PRESSURE
#1 ENGINE RPM (NP)	#2 ENGINE HYDRAULIC PUMP PRESSURE
#2 ENGINE RPM(NP)	INPUT LH CHIP
#1 ENGINE TEMPERATURE (T5)	INPUT RH CHIP
#2 ENGINE TEMPERATURE (T5)	ACCESSORY LH CHIP
MAIN ROTOR SPEED (NR)	ACCESSORY LH CHIP
COLLECTIVE STICK POSITION	INTERMEDIATE TRANSMISSION CHIP
LONG STICK POSITION	TAIL TRANSMISSION CHIP
LATERAL STICK POSITION	MAIN MIDDLE SUMP CHIP
LOAD FACTOR (NZ)	
PITCH ATTITUDE	
ROLL ATTITUDE	
HEADING	
OUTSIDE AIR TEMPERATURE (OAT)	
STATIONARY SWASHPLATE LOAD	
STABILATOR POSITION	
SAS/FPS COMPUTER FAULT	

TABLE V

AH-64A PARAMETERS (625+ Total)

MIL-STD-1553A DATA BUS PARAMETERS (600+ Total)	CRASH DATA PARAMETERS NOT ON BUS (25 Total)
FAULT DETECTION/LOCATION SYSTEM	#1 ENGINE FIRE
TARGET ACQUISITION DESIGNATION SIGHT/PILOT's NIGHT VISION SENSOR	#2 ENGINE FIRE
AIR DATA SENSOR	AUXILIARY POWER UNIT FIRE
30MM GUN	#1 ENGINE RPM (NG)
HELLFIRE MISSILE SYSTEM	#2 ENGINE RPM (NG)
2.75 IN ROCKET SYSTEM	#1 ENGINE RPM (NP)
HEADING ATTITUDE REFERENCE SYSTEM	#2 ENGINE RPM (NP)
INTEGRATED HELMET DISPLAY SYSTEM	#1 ENGINE TEMPERATURE (TGT)
OPTICAL RELAY TUBE	#2 ENGINE TEMPERATURE (TGT)
FLIGHT SYSTEM	STATIONARY TAIL ROTOR CONTROL LOAD
	STATIONARY SWASHPLATE LOAD
	MAIN ROTOR SPEED
	LATERAL STICK POSITION PILOT
	LONGITUDINAL STICK POSITION PILOT
	COLLECTIVE POSITION PILOT
	PEDAL POSITION PILOT
	STABILATOR POSITION
	PRIMARY HYDRAULIC PRESSURE
	UTILITY HYDRAULIC PRESSURE
	#1 ENGINE CHIPS
	#2 ENGINE CHIPS
	MAIN TRANSMISSION #1 CHIPS
	MAIN TRANSMISSION #2 CHIPS
	#1 NOSE GEARBOX CHIPS
	#2 NOSE GEARBOX CHIPS

A key characteristic of the on-board system is the time-tagging of fault data. This process allows analysis of a wide range of data associated with the problem to identify and isolate intermittent faults which are a significant contribution to false removals, repetitive maintenance, and extended manual troubleshooting efforts.

A typical scenario begins with a preflight inspection to ensure that the system is operating and storage space is available. (The recorder has an indication to alert the crew when 80% capacity is reached.) The pilot brings the aircraft into steady-state condition and then presses a button for the system to perform an automatic engine assessment check. The results of this check are reported to the pilot in the form of a go/no go indicator. The actual parametric data is stored for later retrieval and trending. During the mission, the pilot has the option to activate the recorder when he feels something is abnormal. Otherwise, the recorder records only faults, exceedances, and/or parameters that exceed predetermined "windowed" values. Upon return to base, the mechanic checks the recorder for any indication of a fault or exceedance. If the indicator is lit, the mechanic can then use the portable display to retrieve this data only and display it for quick assessment of the aircraft. If further troublshooting is required, the complete data package can be retrieved from the cartridge and decompressed off-aircraft for inspection and analysis. Fault tree logic resident within the potable maintenance aid interacts with the recorded data and the mechanic to help resolve and identify the location of the problem.

If the aircraft lands and no fault or exceedance is indicated, then the mechanic can either download the data from the cartridge or bolt the covers back in (provided the recorder has not reached 80% storage capacity).

The exceedance/fault data which the mechanic can inspect alongside the aircraft can be displayed in various formats. The following figures show current examples of these formats. Fig. 9 lists a series of engine temperature recordings with the allowed time at temperature. When an exceedance has occurred requiring a maintenance action, the appropriate tech manual (TM) reference is cited. In future, more powerful systems, the complete text of the TM can be shown and thus entirely eliminate paper on the battlefield.

ENGINE STATE	(ALLOWABLE SEC) BEFORE TSHOOT	BEFORE MAINT	RECORDED SECONDS #1ENG	#2ENG	TRBLESHOOT/ MAINTENANCE #1ENG	#2ENG
NG<GI T4.5>850	0	12	0	0		
NG>GI T4.5>850	12	60	0	0		
NG>GI T4.5>886	0	60	0	0		
NG>GI T4.5>902	0	55	0	0		
NG>GI T4.5>906	0	50	0	0		
NG>GI T4.5>910	0	46	0	0		
NG>GI T4.5>914	0	42	0	0		
NG>GI T4.5>918	0	38	0	0		
NG>GI T4.5>922	0	34	0	0		
NG>GI T4.5>926	0	30	0	0		
NG>GI T4.5>930	0	26	0	0		
NG>GI T4.5>934	0	22	0	0		
NG>GI T4.5>938	0	18	0	0		
NG>GI T4.5>942	0	15	0	0		
NG>GI T4.5>946	0	12	0	0		
NG>GI T4.5>950	0	0	0	0		

REF: TM55-2840-248-23 PP 1-419 PARA 1-223

Fig. 9. Engine Overtemp Report

Fig. 10 shows a hard landing report based on negative feet per second. Another way of measuring this would be to place a load sensor on the landing gear. By identifying the extent of a hard landing, much confusion as to what inspection and repair tasks are required can be avoided. In addition, a history of hard landings can be trended for an aircraft, better enabling a mechanic to schedule maintenance and to predict potential problems before they occur.

LANDING VERTICAL SPEEDS

	0-2	2-4	4-6	6-8	8-10	10
# LANDINGS	FPS	FPS	FPS	FPS	FPS	FPS
AT SPEED=	3	2	0	0*	0*	0*

TIME OF HARDEST 06:23:17.473

NO VERTICAL SPEEDS > 6 FPS RECORDED
NO SPECIAL INSPECTIONS REQUIRED
REF: TM55-1520-237-23-4 TASK 9 PP 9-16

Fig. 10. Hard Landing Report

Figures 11 and 12 show reports for engine and rotor overspeed, respectively. Fig. 13 is a report for discrete indicators. These discrete indicators are the various caution/advisory data that is displayed in the cockpit. Time-tagging these indicators can greatly help the mechanic in trying to resolve pesky, intermittent failures that often cannot be duplicated on the ground.

ENG SPEED	(ALLOWABLE - SEC'S) BEFORE TSHOOT	BEFORE MAINT	RECORDED SECONDS #1ENG	#2ENG	TRBLESHOOT/ MAINTENANCE #1ENG	#2ENG
NP>110%	—	12	14.7	2.3	M	
NP>113%	0	12	0.0	1.8		T
NP>130%	—	0	0.0	0.0		

ENGINE OVERSPEED ACTION REQUIRED: (M) (T)

REF: TM55-2840-248-23 PP 1-419 PARA 1-222A

Fig. 11. Engine Overspeed Report

```
        SIKORSKY UH60A / LSI IFIDS NVM SUMMARY
            82-23709  14:30:39   1/15/87

---- NR OVERSPEED REPORT --------------------------
                            ROTOR SPEED RANGE
     102- 107- 112- 117- 122- 127- 132- 137-   >
     107% 112% 117% 122% 127% 132% 137% 142% 142%
REC'D                            *         *    *
MIN=   0.0

       NO ROTOR SPEEDS > 127% RECORDED
       NO SPECIAL INSPECTIONS REQUIRED
       REF: TM55-1520-237-23-4 TASK9  PP 9-14.1
```

Fig. 12. NR Overspeed Report

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      SIKORSKY UH60A / LSI IFIDS NVM SUMMARY
          82-23709  14:30:39   1/15/87

---- DISCRETE REPORT -----------------------------

NO.1 ENGINE OIL PRESSURE      NO HITS
NO.1 ENGINE CHIP DETECTOR     NO HITS
NO.2 ENGINE OIL PRESSURE      NO HITS
NO.2 ENGINE CHIP DETECTOR     NO HITS
ENGINE FIRE                   NO HITS
APU OIL PRESSURE              NO HITS
SAS WARNING                   NO HITS
NO.1 HYDRAULIC PUMP PRESSURE  NO HITS
NO.2 HYDRAULIC PUMP PRESSURE  NO HITS
INPUT MODULE LH CHIP DETECT   NO HITS
ACCESS MODULE LH CHIP DETECT  NO HITS
INPUT MODULE RH CHIP DETECT   NO HITS
ACCESS MODULE RH CHIP DETECT  NO HITS
INT TRANSMISSION CHIP DETECT  NO HITS
TAIL TRANSMISSION CHIP DTECT  NO HITS
MAIN SUMP PUMP CHIP DETECT    NO HITS
SAS/FPS COMPUTER FAULT        NO HITS
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Fig. 13. Discrete Report

BENEFITS

The objectives of such an integrated diagnostic approach are many: reduce repetitive and incorrect maintenance, reduce the requirement for special inspections and special purpose test and support equipment, provide adequate information to allow mechanic cross training and MOS consolidation, provide capabilities for card level fault isolation (two-level maintenance concept), provide for critical parts tracking, increase overall aircraft safety, etc. Most of these objectives are being realized through data processing and analysis off-aircraft. However, a more efficient manner of accomplishing increased aircraft safety would be through an on-board system which integrates all available flight information with the condition monitoring system. Just such a system has been defined in a recent NASA effort titled "An Artificial Intelligent Approach to On-Board Fault Monitoring and Diagnosis for Aircraft Application."

AI MONITORING SYSTEM

INTRODUCTION

The above research effort was initiated to identify guidelines for automation of on-board fault monitoring and diagnosis and associated crew interfaces. The effort began by determining the flight crew's information requirements and the various reasoning strategies they use. Based on this information, a conceptual architecture was developed that encompasses all aspects of the aircraft's operation, including navigation, guidance and control, and subsystem status. This architecture has two facets: the organization of flight domain knowledge and the problem solving process that uses this knowledge for condition monitoring and diagnosis.

ORGANIZATION OF FLIGHT DOMAIN KNOWLEDGE

Fig. 14 depicts the various categories and interconnectives for flight domain knowledge. Each level in the goal hierachy is subservient to the one above it in the sense that it supplies the means of achieving the goals passed down to it from above. Each level provides a goal which the level beneath it must attempt to achieve. It is important to notice that there may be many different ways of achieving a particular goal; all are correct. The knowledge in each level must contain information not only on how to describe a way of achieving a particular goal but also (and perhaps more importantly) on how to determine if a particular means can or cannot satisfy a goal.

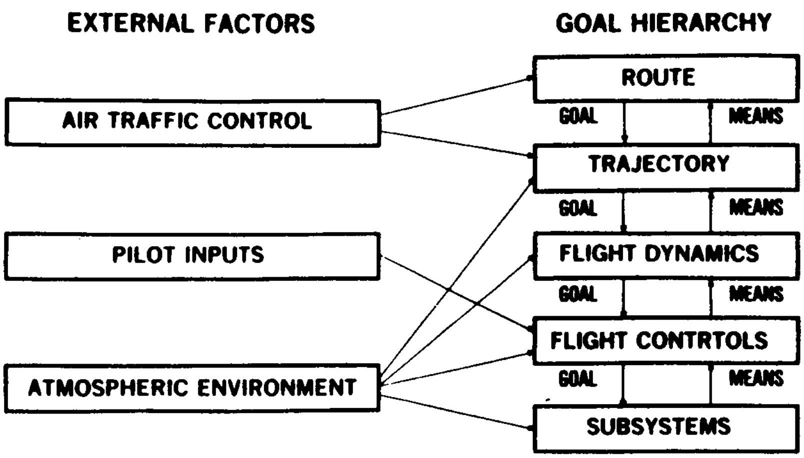

Fig. 14. Organization of Flight Domain Knowledge

There are categories of information which are not levels in the goal hierarchy but are external inputs to different levels. The atmospheric information (such as, wind, temperature, and pressure) is a set of inputs to various levels which must be taken into account when determining how to achieve a goal. Another such category is actual pilot actions for setting control inputs, switch settings, and so on. Still another category is information and instructions received from Air Traffic Control (ATC) in the form of ascent, descent, and heading commands.

This organization of flight domain information corresponds to a taxonomy of the faults in flight which might lead to accidents. The term "fault" refers to any problem which may result in some goal not being achieved if not corrected or compensated, as well as failure in a physical system. This is an important distinction in the flight domain because problems such as wind shear or the pilot giving incorrect inputs can endanger the aircraft just as much as a physical system failure.

FAULT MONITORING AND DIAGNOSTICS FRAMEWORK

A framework for the fault monitoring and diagnosis process was developed as a result of interviewing aircraft pilots and examining pilot handbooks. Although this framework is described in the context of a specific domain (i.e., engines), it is believed to be a general framework for fault monitoring and diagnosis. It was not intended to model the cognitive process that humans use for fault diagnosis but to facilitate development of representative and remaining methods for fault diagnosis and its automation.

The components of the framework are shown in Figure 15 as well as examples of the input and output for each component. As shown, the fault monitor, the fault diagnosis process, and the interface mechanism to the flight crew are all separate components. The purpose of the fault monitor is to detect when a fault occurs by examining sensor readings and generating symptoms which represent the abnormal values. These symptoms are the input to the fault diagnosis process, whose purpose is to suggest fault hypotheses which isolate the cause of the symptoms. The diagnosis process is divided into three stages, each with a different reasoning strategy and representation. Stages are organized in order of increasing computational and representational complexity, much like humans use diagnosis strategies. Each stage is entered when prior stages are unsuccessful at diagnosing the current failure. The interface mechanism displays the diagnoses in an appropriate format to the flight crew. The interface mechanism must be sensitive to flight phase and crew workload.

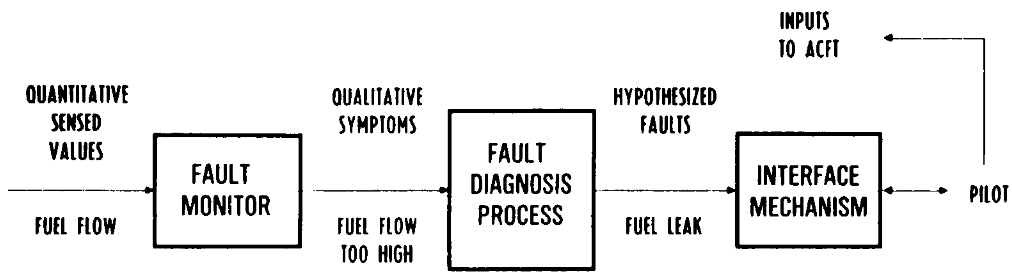

Fig. 15. Fault Monitoring and Diagnosis Process

The fault diagnosis process has several stages, as shown in Fig. 16. Each stage uses different representations and reasoning strategies. In the first stage, the symptoms are compared to fault-symptom association known a priori. These associations are a compilation of knowledge about known faults and their behavior. This stage corresponds to traditional expert systems approaches and is attempted first because it quickly identifies the most commonly occurring faults.

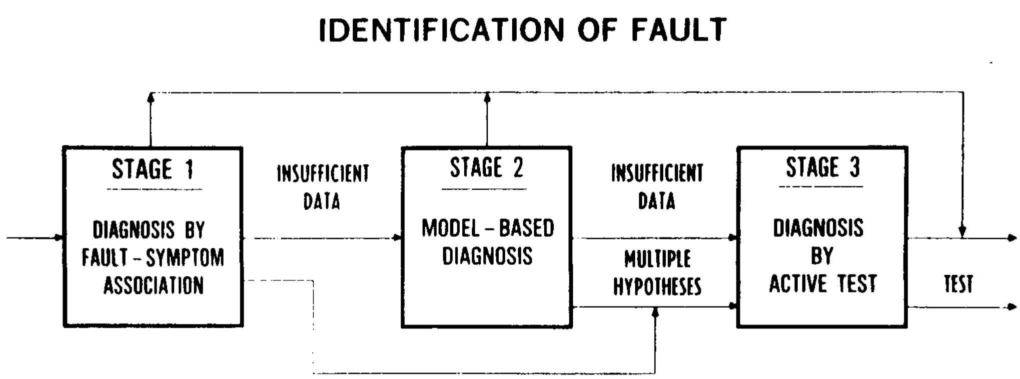

Fig. 16. Fault Diagnosis Stages

The second stage of the diagnosis process occurs when the current symptoms fail to correspond to a known fault. The purpose of the reasoning at this stage of the diagnosis process is to localize the failure and to generate as much information about the fault as possible. To generate the desired information about the fault, the diagnostic reasoning in the second stage focuses on how the physical system works rather than on how the system fails, as was done in the first diagnosis stage. Models of functional and physical structure are used to provide the knowledge on how the system works.

Since all parameters are not observable and other factors such as system feedback are present, localization of the failure may not be possible without further information. In this situation, the third diagnosis stage is entered. Depending on the domain, performing tests to obtain further information may be done passively or actively. The third stage is responsible for proposing tests to obtain additional information, whether the tests are active or passive. In either case, the fault diagnosis system may be able to use the results to identify faults.

Implementation of this architecture is under development. A computer program called INFAMOS (Intelligent Fault Monitoring System) is being developed. The fault diagnosis system is being implemented in a computer program called DRAPHYS (Diagnostic Reasoning About Physical Systems). The first application of these models will be an aircraft turbofan engine.

FUTURE NEEDS

Most of the technology required to implement effective integrated diagnostics and other maintenance aids is available today. To be truly effective, several things must happen. First, this technology must be applied both to mission equipment and to aircraft subsystems. This requires a systems level design of the performance monitoring equipment, including subcontractor supplied BIT, in order to ensure complete coverage. Detail appropriate to the maintenance concept for the system must be available from the monitoring subsystem. An aircraft designed for three-level maintenance only requires fault isolation to the LRU level whereas, a two-level maintenance concept requires fault isolation to the module or card level. This places an increased level of complexity for the testability design of the component.

Sensor development is required to improve not only accuracy but also repeatibility and reliability. An integrated diagnostic system may have the most efficient architecture possible with the most advanced and tested software logic incorporated; however, the answers will always be wrong if the inputs are not correct. In addition, development is needed in the area of load measurements where current strain gauges are high bandwidth signals which require preprocessing or data extraction prior to transmission to a data bus or flight recorder.

A final and really most important area is the development of the discrimination logic between good and bad components. In the mechanical system with its myriad of failure mode combinations and resulting symptoms, complex systems currently prohibit simple and direct techniques to determine when a component has reached its expected life. Identical components operated under similar conditions may still exhibit different symptoms for identical failure modes. Vibration analysis has been hindered by this phenomenon primarily due to the intense processing requirements and overall sophistication of the techniques. However, as embedded processors become more powerful and memory less expensive, new analysis techniques can be implemented in attractive designs. What is still needed are the test methodologies to "nail down" the good versus bad signatures and how to use this data to alert the mechanic of impending failures prior to catastrophy but yet allow maximum usage of the component.

CONCLUSION

Application of these integrated design concepts to the next generation aircraft will provide substantial improvements in combat sustainability and in reducing logistic burdens and operating and support costs. Measured against today's systems, the next generation can be more capable, with the added complexity that capability demands, and still require less reserves both in personnel and material. All the technologies required to implement these designs are emerging and will be mature within the next few years. The challenge in achieving these gains is management of larger development or product improvement integration teams, and imposing system level design requirements up front to ensure that design goals are met.